GAU-2733

#4 Priority Paper 8/7/98

OIPE JC55 AUG 03 1998 PATENT & TRADEMARK OFFICE

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of

DORAN et al

Serial No. 09/083,966

Filed: 26 May 1998

Atty. Ref.: 604-445

Group: 2733

Examiner:

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For: DISPERSION MANAGEMENT SYSTEM FOR SOLITON OPTICAL TRANSMISSION SYSTEM

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August 3, 1998

Honorable Commissioner of Patents
and Trademarks
Washington, DC 20231

SUBMISSION OF PRIORITY DOCUMENT

Sir:

It is respectfully requested that this application be given the benefit of the foreign filing date under the provisions of 35 U.S.C. §119 of the following, a certified copy of which is submitted herewith:

Application No.	Country of Origin	Filed
9524203.8	Great Britain	27 November 1995

Respectfully submitted,

NIXON & VANDERHYE P.C.

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290036

The Patent Office

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Cardiff Road
Newport
South Wales
NP9 1RH

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Dated 17th June 1998.

Patents Form 1/77

Patents Act 1977
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1/77

29NOV95 E158677-1 D02111
P01/7700 25.00

Request for grant of a patent

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27 NOV 1995

The Patent Office

Cardiff Road
Newport
Gwent NP9 1RH

1. Your reference	137318
2. Patent application number *(The Patent Office will fill in this part)*	9524203.8
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	BRITISH TECHNOLOGY GROUP LTD 101 NEWINGTON CAUSEWAY LONDON SE1 6BU
Patents ADP number *(if you know it)*	
If the applicant is a corporate body, give the country/state of its incorporation	UNITED KINGDOM 0651212300\
4. Title of the invention	OPTICAL COMMUNICATIONS
5. Name of your agent *(if you have one)*	R CULLIS
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	BRITISH TECHNOLOGY GROUP LTD 101 NEWINGTON CAUSEWAY LONDON SE1 6BU
Patents ADP number *(if you know it)*	01021666002

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THE PATENT OFFICE
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	Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number			

	Number of earlier application	Date of filing *(day / month / year)*
7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application		

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	YES

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	4
Claim*(s)*	
Abstract	
Drawing*(s)*	3

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Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature R CULLIS Date 27 NOVEMBER 1995
AGENT FOR THE APPLICANTS

12. Name and daytime telephone number of person to contact in the United Kingdom C NICHOLLS 0171 403 6666

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Optical communications

This invention relates to optical communications and, in particular, to optical communications systems in which information is transmitted by soliton or soliton-like pulses.

Laboratory demonstrations have recently been reported of soliton transmission in systems where the dispersion was not uniformly anomalous along the fibre, instead being periodically compensated by fibre of opposite (normal) sign dispersion. In this manner transmission was achieved at 20Gb/s over 9000km in a recirculating loop, and 8100km in a straight line experiment. These figures are substantially in excess of what has previously been achieved without the use of soliton control techniques such as sliding filters and synchronous modulators. While it is thus clear that there are significant benefits to be gained from adopting dispersion management in soliton systems, to date there has been little conceptual explanation of the mechanisms behind this improvement.

The correct selection of dispersion is a critical issue in the design of amplified long haul optical communication systems. In the case of soliton formatted data, it is dictated by compromise between the desire to minimise timing jitter problems (implying low dispersion), and the need to maintain adequate energy per bit for successful detection. As the energy needed to form a soliton in a uniform fibre is proportional to the dispersion, the latter constraint places a lower limit on the permitted dispersion. Dispersion management is a technique in the context of non-return-to-zero (NRZ) formatted data in which fibres of opposite sign dispersions are concatenated together. This produces a high local dispersion at any given point,, and yet a low path-average dispersion. We have found that, by adopting a suitable dispersion management scheme for soliton or soliton-like transmission, it is possible to increase the soliton energy substantially compared with the equivalent uniform fibre with equal path-average dispersion.

According to the present invention there is provided a dispersion management system for soliton or soliton-like transmission in which the duration of a dispersion compensation phase is short in comparison with the propagation interval in the remainder of the system.

Preferably the system excludes arrangements in which the dispersion map of one fibre is substantially closer to zero than that of its complementary fibre.

The invention will be particularly described with reference to the accompanying drawings in which:

Figure 1 is a dispersion compensation map;

Figure 2 shows the pulse profile at the beginning of each unit cell in a dispersion managed system. The dispersion map comprises alternating 100km fibres with dispersions of -3ps^2/km and +2.8ps^2/km;

Figure 3 shows the evolution of a over one period of the dispersion compensation cycle, and

Figure 4 shows the energy required to launch a 20ps FWHM soliton in dispersion managed system with alternating 100km length fibres chosen such that the path-average dispersion remains at -0.1ps^2/km.

Our work is based upon numerical integration of the Nonlinear Schrödinger Equation (NLS), using the dispersion map shown in Figure 1. This comprised equal lengths of alternating normal and anomalous fibres, although the unit cell is defined to start and end at the mid point of one of the fibres. In all the examples presented each of the fibres will be 100km long, and the path average dispersion -0.1ps^2/km. The nonlinear coefficient was taken to be 2.65rad/W/km. To simplify the problem we have chosen to neglect loss and high order dispersion throughout.

We have confirmed the existence of quasi-stable soliton or solitary wave solutions to this dispersion map. Figures 2 and 3 show the observed behaviour when the dispersion values alternated between -3.0ps^2 /km and +2.8pS^2 /km, and a 20ps FWHM Gaussian pulse of peak power 650μW was launched into the fibre. Figure 2 shows the intensity profiles at the start of each unit cell; it can be seen that the pulse profile at these points remains unchanged over successive cycles of the dispersion map. The evolution within one unit cell is shown in Figure 3, the pulse alternately compressing and dispersing as the sign of the dispersion is switched. The power spectrum remains essentially unchanged within the unit cell.

There are three constraints which must be satisfied to obtain stable solutions to the periodic dispersion map. Firstly, the path average dispersion must be anomalous, in order that the Kerr induced spectral broadening can be compensated. Secondly, the period of the dispersion compensation cycle must be short compared to the nonlinear length of the

system. Finally, dispersion maps in which one of the fibres is much closer to zero dispersion than the other should be avoided. as otherwise energy is rapidly coupled out of the pulse into dispersive waves.

The advantages conferred by a dispersion management scheme on soliton communications stems from the fact that more energy is required to launch a stable pulse than in the equivalent uniform system with equal path average dispersion. This is demonstrated in Figure 4, which plots the pulse energy of the stable solution as a function of the difference between the dispersion values of the two individual fibres. Greater differences between the two fibres results in more energy being required to form a stable pulse; we have also found that lengthening the unit cell's period (with a given pair of dispersion values) increases the required energy. The mechanism behind this increased energy requirement can be understood from the intensity profile within the unit cell, figure 3. Due to the cycle of dispersive broadening and compression, the peak power of the pulse is generally lower than the initial launch power. Therefore the rate of self phase modulation (SPM) is reduced compared to the equivalent uniform fibre, and so more energy is required to balance the path-average dispersion. In the frequency domain, the process could be construed as a reduction in the efficiency of four wave mixing. of which SPM is a special case.

Another highly novel feature of these solitary waves is that their pulse shapes are not the hyperbolic secants of regular optical fibre solitons. The example pulse profile which we have displayed is almost exactly Gaussian in nature, however this is only a special case for that particular dispersion map. As the dispersion variation is increased there is a transition from the uniform fibre hyperbolic secant soliton (time-bandwidth-product 0.32) to Gaussian (0.44) form, and then to pulse shapes with higher still time-bandwidth-products. An interesting connection can be made at this point with the "stretched pulse' design of mode-locked fibre laser. These incorporate cavities with two opposite signs of dispersion and also produce Gaussian shaped pulses.

In cases of soliton or soliton-like transmission in dispersion compensated fibres employing a configuration with zero path average dispersion, undistorted pulse propagation was obtained in this situation due to the presence of optical filters in the recirculating loop. The stable pulses then arose from balancing SPM against filtering,

rather than SPM against the path-average dispersion.

The technique of dispersion management has the potential to make a significant impact of the realisation of soliton communication systems. It provides major performance benefits, and has the distinct advantage of requiring only passive components. While, in a preferred embodiment, we have used equal lengths of two different fibres, alternative embodiments may use discrete dispersion compensators fabricated from highly dispersive materials. The adoption of dispersion management represents a convergence between the techniques used in soliton and NRZ formatted transmission.

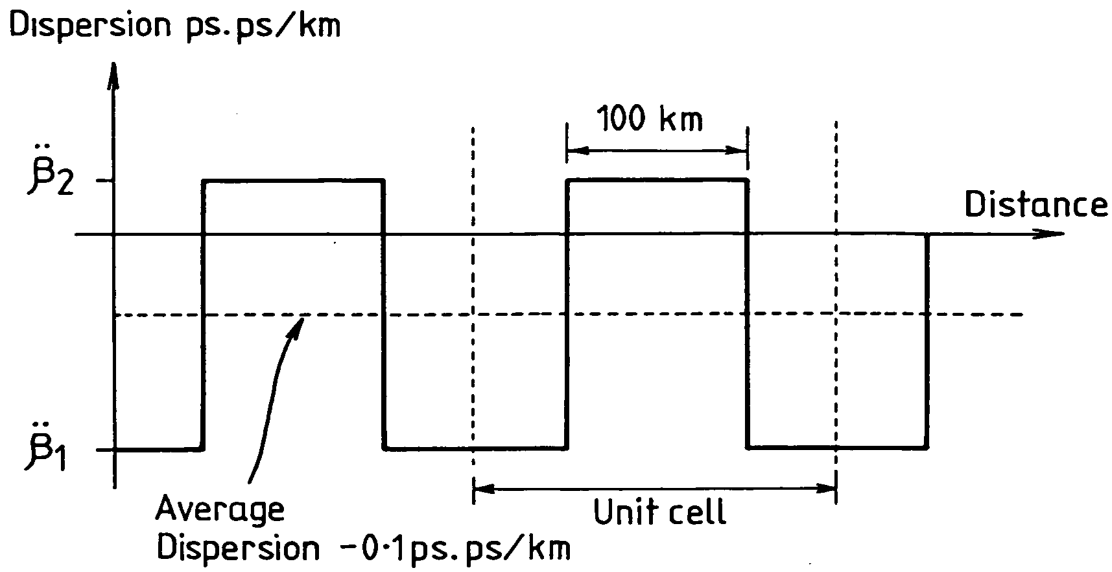
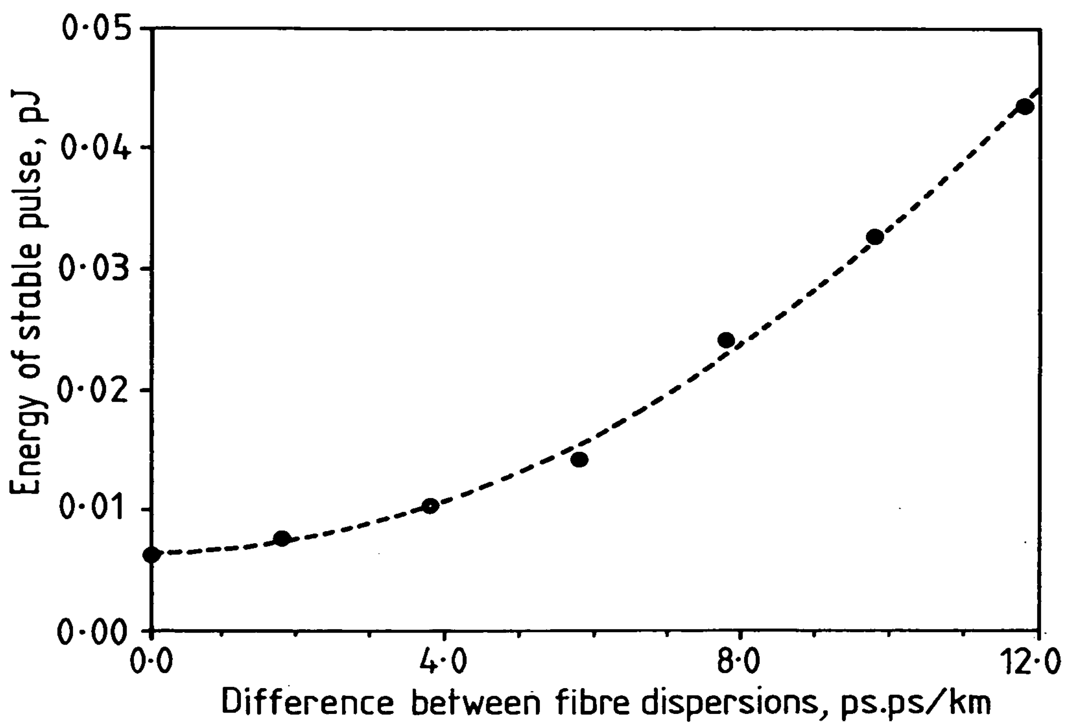

Dispersion ps.ps/km
100 km
$\ddot{\beta}_2$
Distance
$\ddot{\beta}_1$
Average
Dispersion -0·1ps.ps/km
Unit cell

Fig. 1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0·04
0·03
0·02
0·01
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Energy of stable pulse, pJ
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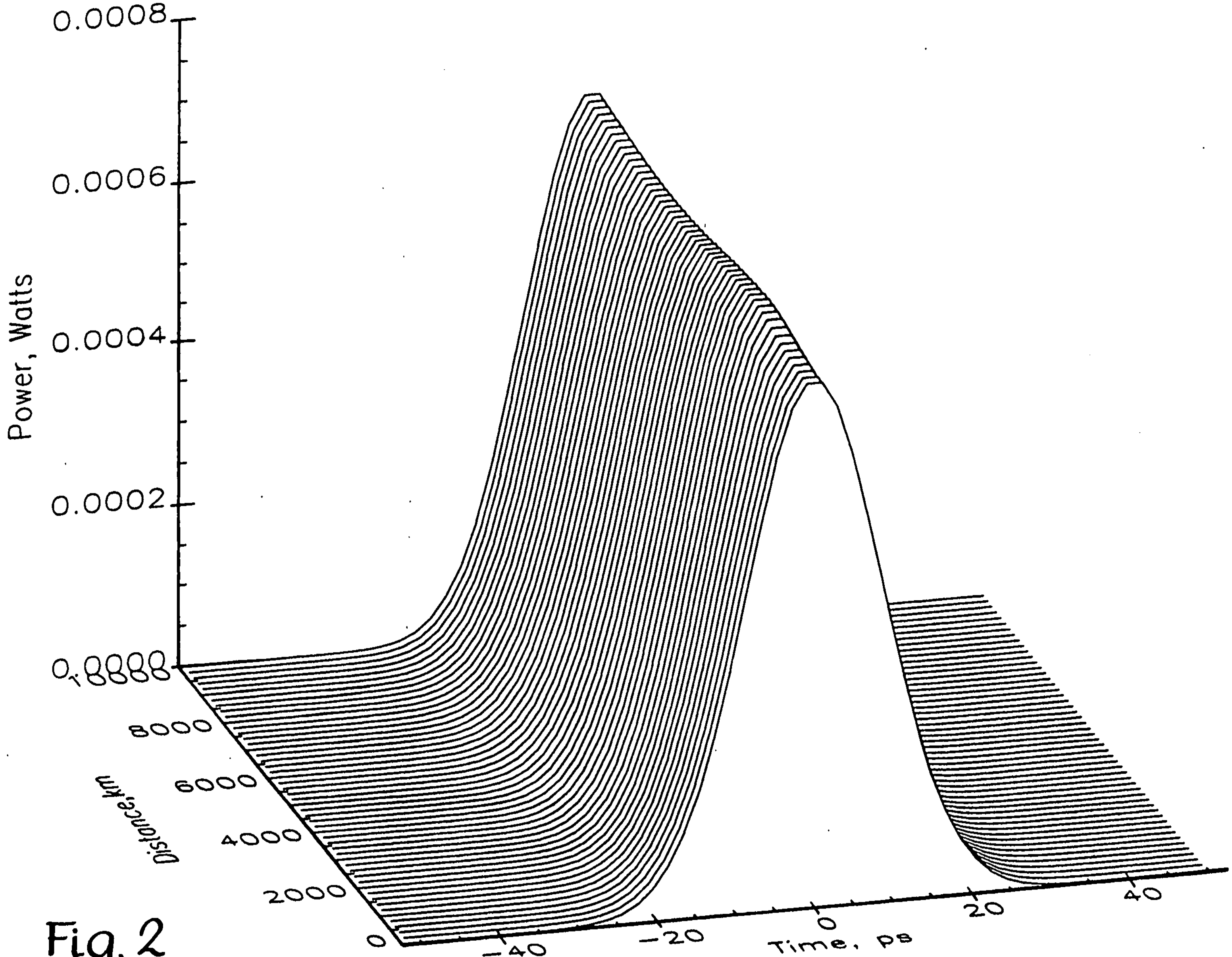
8·0
12·0
Difference between fibre dispersions, ps.ps/km

Fig. 4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0.0004
0.0002
0.0000
10000
8000
6000
4000
2000
0
Distance,km
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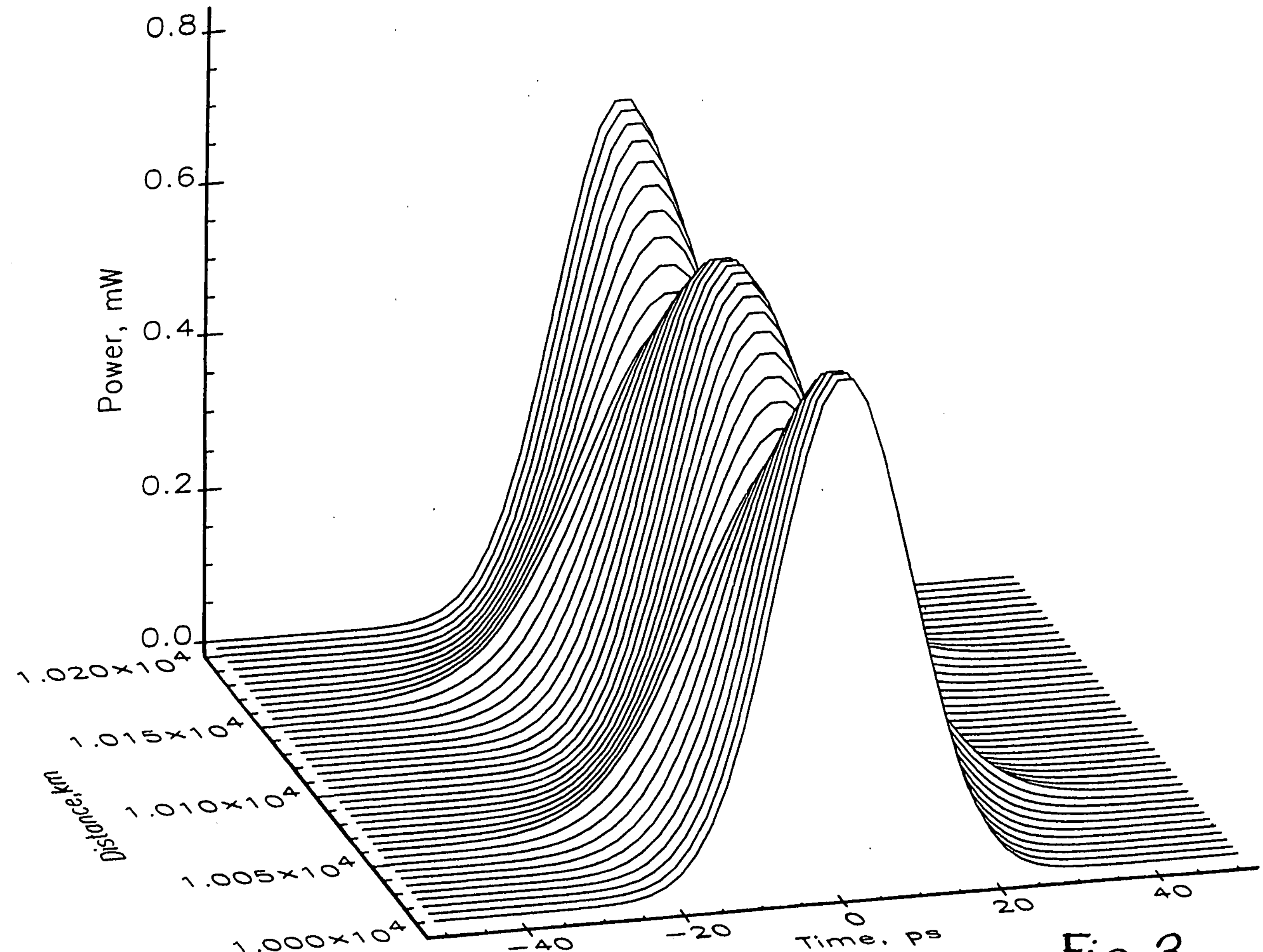
-20
0
20
40
Time, ps

Fig. 2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0.6
0.4
0.2
0.0
Power, mW
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1.015×10^4
1.010×10^4
1.005×10^4
1.000×10^4
Distance,km
-40
-20
0
20
40
Time, ps

Fig. 3

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